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ABSTRACT

This vocational physics individualized student instructional module on jacks (simple machines used to lift heavy objects) contains student prerequisites and objectives, an introduction, and sections on the ratchet bumper jack, the hydraulic jack, the screw jack, and load limitations. Designed with a laboratory orientation, each section consists of explanatory material with illustrative drawings, an experiment accompanied by a data sheet, suggested audiovisual materials, and review questions. (NJ)

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ED131291

JACKS--A STUDY OF SIMPLE MACHINES

by Ralph Parsons

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Winston-Salem, North Carolina

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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PRE-REQUISITES

Before beginning this module the student should be able to work the following types of mathematical problems.

1. Given several numbers, calculate the average of their values.
2. Given the diameter of a circle, calculate its area and circumference.
3. Given the diameter and height of a cylinder, calculate its lateral surface area.
4. Make conversions between the following units:
   (a) inches - feet
   (b) ounces - pounds
   (c) grams - kilograms

The student should also be able to read the scale of an English/metric rule and the scale of a spring balance.

OBJECTIVES

After completing this module, the student should be able to recognize the definitions and applications of the following terms. Testing will be by multiple choice questions.

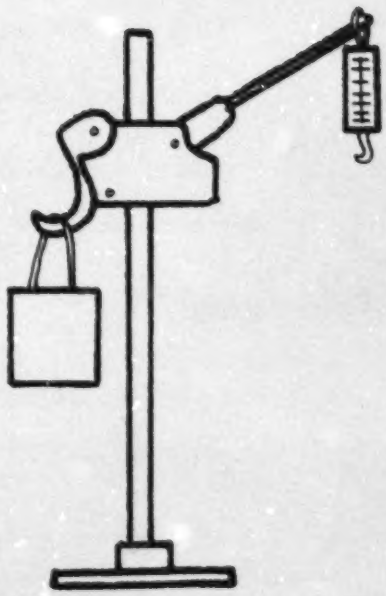
1. Weight
2. Simple Machine
3. Lever
4. Inclined Plane
5. Hydraulic Press
6. Actual Mechanical Advantage
7. Theoretical Mechanical Advantage
8. Work
9. Pressure
10. Energy
11. Friction
12. Efficiency
13. Torque
14. Stress
15. Tensile Stress
16. Compressive Stress
17. Shear Stress
18. Ultimate Strength
19. Elasticity
20. Safety Factor

The student should also be able to solve numerical problems involving the following quantities.

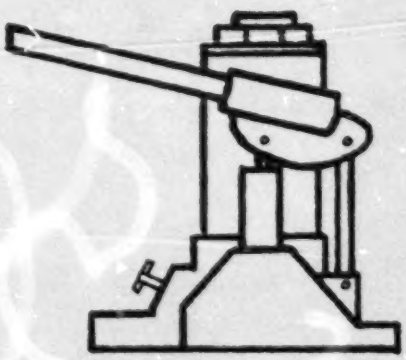
1. Actual Mechanical Advantage
2. Theoretical Mechanical Advantage
3. Work
4. Pressure
5. Efficiency
6. Torque
7. Stress

The system for assigning grades to levels of performance will be determined by the instructor.

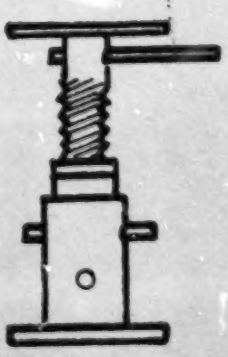
I. INTRODUCTION



Jacks are used for pushing heavy objects. In this module we will be concerned with pushing objects straight up away from the earth. Objects are held to the earth by an invisible force field called gravity. Gravity exerts large forces on massive bodies and lesser forces on less massive bodies. The force that gravity exerts on objects is called the weight of the object. In order to pry an object away from the earth we must exert a slightly greater force upward than gravity is exerting downward. Once the object begins to move upward we can keep it moving by exerting a force exactly equal to its weight.



When lifting one end of a car to change a tire, a thousand pounds or more of force is required. It is possible for one person to exert this large force by using a device called a jack. A jack is one, or a combination of, simple machines whose purpose is to lift a large weight. The small force exerted on a jack by a person is multiplied many times by the jack into a force large enough to lift cars, trucks, and even buildings.



SIMPLE MACHINES

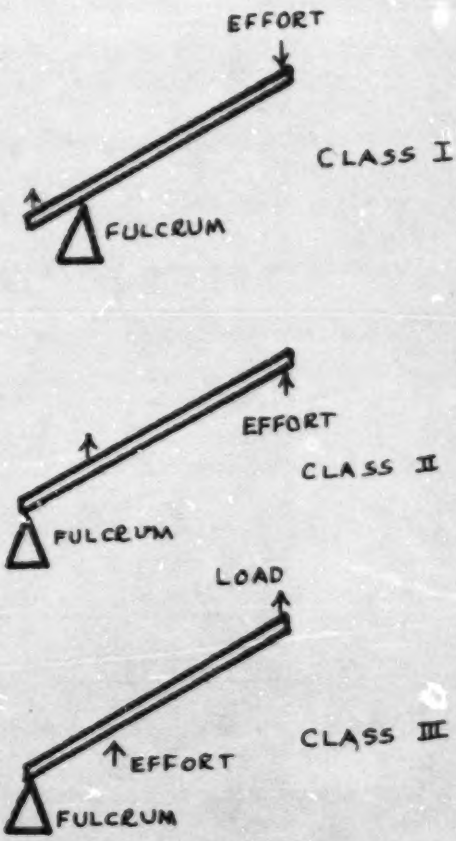
The jack is only one example of the usefulness of a group of devices known as simple machines. Simple machines do not do any work themselves. Simple machines simply increase the amount of force you are able to apply to a load or increase the distance that the load is moved. Simple machines may be divided into three groups: levers, inclined planes, and hydraulic presses.

THE LEVER

A lever is a rigid bar that is free to pivot about some point called a fulcrum and is used to increase the force applied to a load or increase the distance that the load is moved.

The effort is the force applied to the lever and the load is the force that the lever puts out.

Some applications of the lever that are not obvious are the wheel and axle, and gear systems that are used to increase force or distance, and the block and tackle, used to increase force.



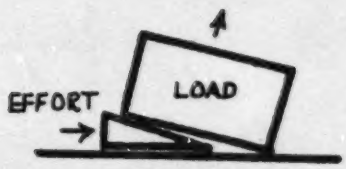
THREE CLASSES OF LEVERS — THE ARROWS INDICATE THE LOCATION OF THE LOAD AND EFFORT AND THE DIRECTION IN WHICH THEY MOVE.

APPLICATIONS OF THE LEVER

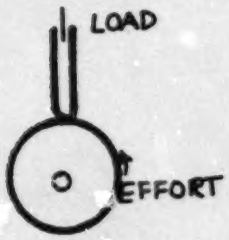
THE INCLINED PLANE

An inclined plane is a surface inclined at an angle with the vertical. It is so simple that it is difficult to think of it as a machine. From your own experience, however, you know that heavy loads are much easier to move up an incline or ramp than they are to lift or push straight up.

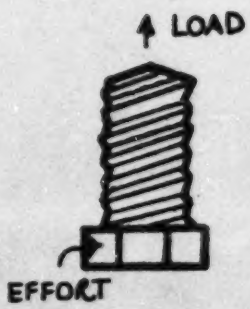
The wedge is an inclined plane and a cam is a rotating wedge. A screw is simply an inclined plane wrapped around a cylinder.



WEDGE

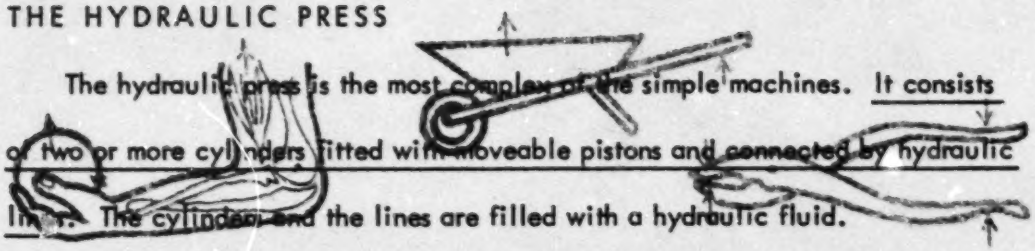


CAM



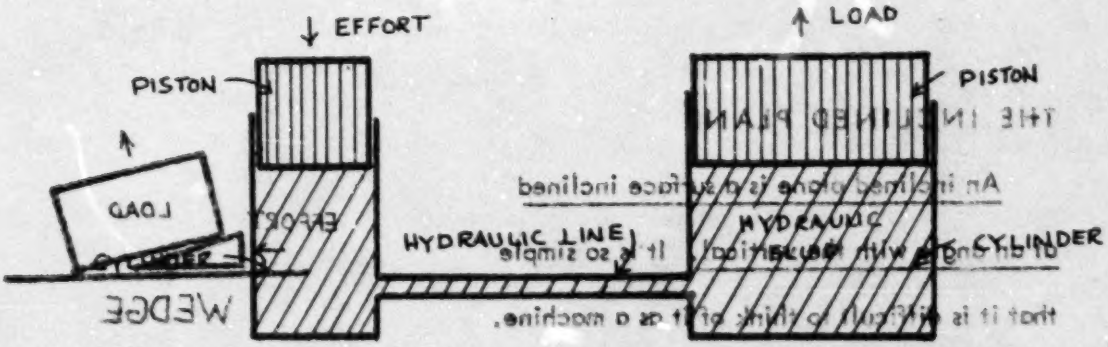
SCREW

THE HYDRAULIC PRESS



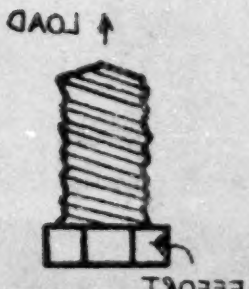
The hydraulic press is the most complex of the simple machines. It consists of two or more cylinders fitted with moveable pistons and connected by hydraulic lines. The cylinders and the lines are filled with a hydraulic fluid.

The principle of the hydraulic press is used in hydraulic jacks and lifts, earth-moving machines and metal-forming presses.



A SIMPLE HYDRAULIC SYSTEM

CAM



SCREW

AUDIO-VISUAL MATERIALS

"Simple Machines," a 16mm film.

REVIEW QUESTIONS

1. What is weight?

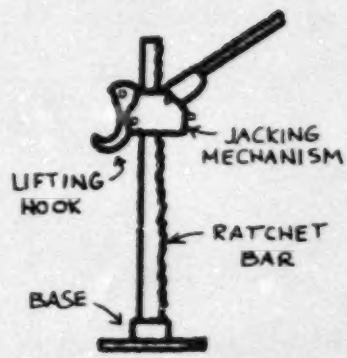
2. How much force must be exerted to lift an object with a weight of 1 pound?

3. What is the purpose of a simple machine?

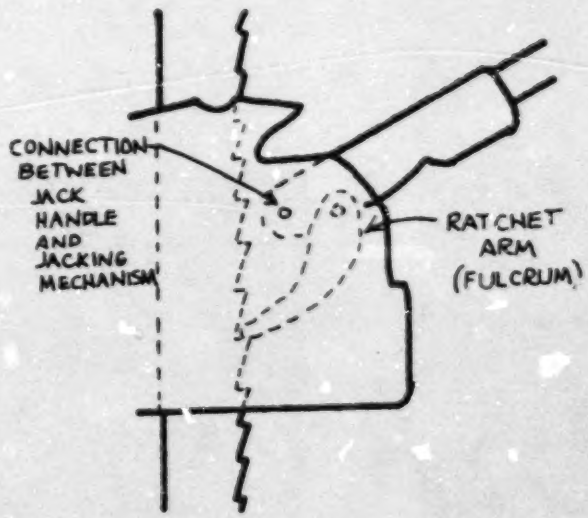
4. What are the three main types of simple machines?

II. THE RATCHET BUMPER JACK

Possibly the most common type of jack is the ratchet bumper jack. Its main parts are: (1) a base, (2) a ratchet bar, and (3) a jacking mechanism. The jacking mechanism includes a hook for lifting the load, a lever, and ratchet arms. The ratchet arms serve as the fulcrum for the lever and prevent downward motion of the jacking mechanism.



When the jack handle is pushed downward by an effort force, it rotates about a fulcrum provided by one of the ratchet arms. As it rotates, the end of the jack handle inside the jacking mechanism is lifted, taking the jacking mechanism with it.



MECHANICAL ADVANTAGE

An important property of a jack, or any simple machine, is its mechanical advantage. The mechanical advantage is the factor by which a machine can multiply the force put into it. Suppose you exert an effort of 100 pounds at the end of a jack handle and the jack lifts a load of 1,000 pounds. The effort you used was multiplied by a factor of 10, so we say the mechanical advantage is 10.

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}}$$

For example, suppose that to lift a load of 75 pounds with a certain machine an effort of 3 pounds is required. Find the mechanical advantage of the machine.

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}}$$

$$= \frac{75 \text{ POUNDS}}{3 \text{ POUNDS}}$$

$$= 25$$

Do Experiment No. 1 to find the mechanical advantage of a ratchet bumper jack.

Experiment No. 1

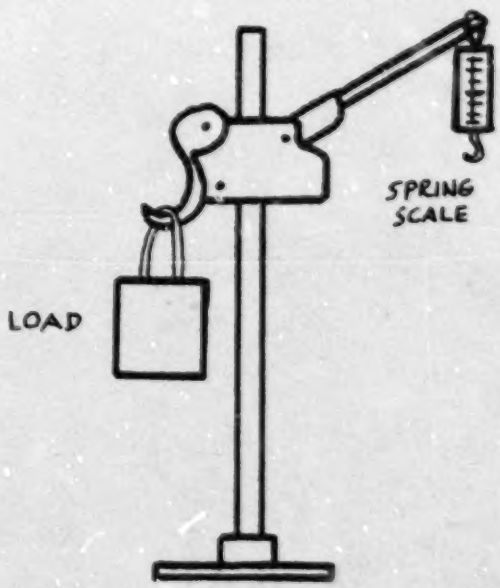
MECHANICAL ADVANTAGE OF THE RATCHET BUMPER JACK

Finding the mechanical advantage of a machine by experiment is simple.

1. Measure the amount of effort required to lift a known load. This measurement is easily made with a spring scale.

2. Divide the effort into the load. Both the effort and the load must be measured in the same units such as both in pounds, both in ounces, or both in grams.

Take data to determine the mechanical advantage using three different loads and two different jack handle lengths. Use loads of approximately 25, 50, and 75 pounds. The actual loads you use may differ from these values depending on what is available to you. If you do not know the weight of your loads, weigh them on something such as a bathroom scale. One jack handle length used should be approximately twice the other length.



Record your loads to the nearest pound or kilogram and your effort to the nearest ounce or gram. Fill in the data sheet.

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EXPERIMENT NO. 1 DATA SHEET Name _____

Mechanical Advantage of the Ratchet Bumper Jack

(Show all calculations and answers to questions on a separate sheet.)

I. Jack Handle Length = _____ inches or _____ centimeters

Weight Being Lifted (Load) In Pounds	Force Required (Effort) In Ounces	Average Load (Pounds)	Average* Effort (Ounces)	Mechanical Advantage

* Don't forget to convert the ounces to pounds before dividing.

II. Jack Handle Length = _____ inches or _____ centimeters

Weight Being Lifted (Load) In kilograms	Force Required (Effort) In grams	Average Load (kilograms)	Average Effort (grams)	Mechanical Advantage

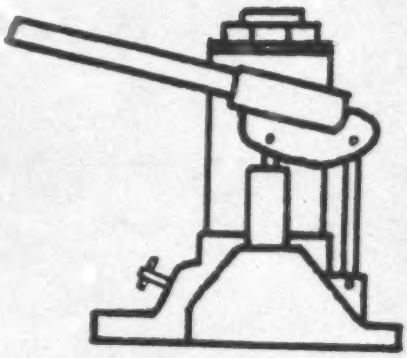
QUESTIONS

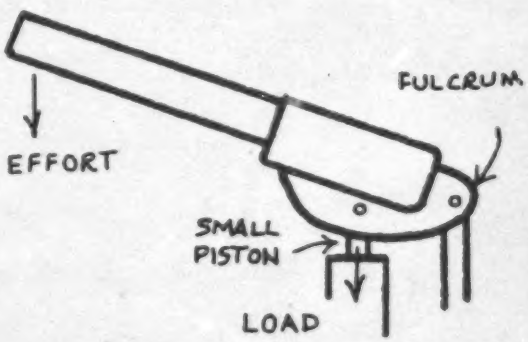
1. How did the different loads affect the mechanical advantage?

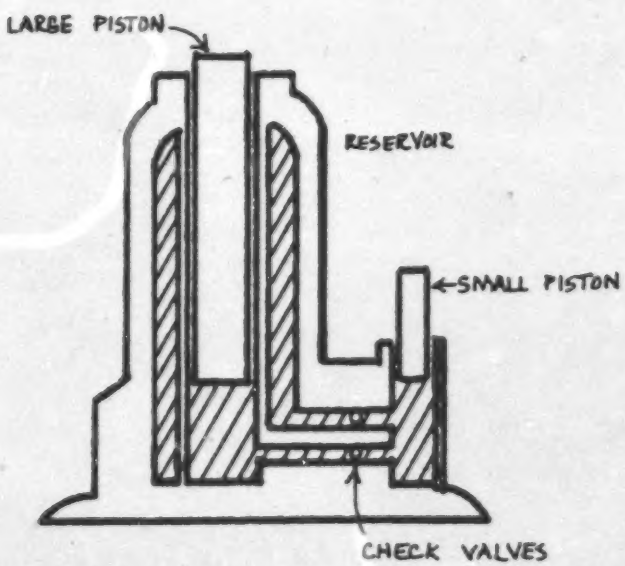
2. How did the different jack handle lengths affect the mechanical advantage?

III. THE HYDRAULIC JACK

The Hydraulic jack is a combination of two simple machines--the lever and the hydraulic press. The lever part of the jack is used to apply a force to a small piston. The small piston applies a force to hydraulic fluid, increasing the pressure in the fluid. The increase in pressure is transmitted through the fluid to a large piston. The fluid exerts a force on the large piston which lifts a load.







Both the lever and the hydraulic system of the hydraulic jack have their own mechanical advantages. The mechanical advantage of jack is the product of these individual mechanical advantages.

THEORETICAL MECHANICAL ADVANTAGE OF THE LEVER

If is possible to predict the mechanical advantage of a machine just by knowing certain dimensions of the of the machine. This prediction is called the theoretical mechanical advantage. It is not necessarily the same as the actual mechanical advantage which if found by measuring the effort required to lift a known load. Theoretical mechanical advantage is calculated from the assumption that the work that a machine puts out when lifting a load is the same as the work that was put into the machine. That brings up a new concept-- WORK.

Work is done on an object when a force is applied to it that causes it to move. The amount of work done is the product of the force applied and distance moved.

WORK = FORCE X DISTANCE

So, if the force is measured in pounds and the distance in feet, the unit of work is the foot-pounds. If the force is measured in kilograms and the distance in meters, the unit of work is the joule.

Consider the situation when you jack up a car. Work is done on the jack because a force is applied to it that causes the jack handle to move. Work is done by the jack because it applies a force to the car that causes it to move upward.

If the work done on the jack is equal to work done by the jack then,

EFFORT X DISTANCE MOVED BY EFFORT = LOAD X DISTANCE MOVED BY LOAD.

Consider an example where an effort of 50 pounds moved a distance of 2 feet causes a load of 1,200 pounds to move 1 inch.

$$50 \text{ POUNDS} \times 2 \text{ FEET} = 1{,}200 \text{ POUNDS} \times 1/12 \text{ FEET}$$

$$100 \text{ FOOT-POUNDS} = 100 \text{ FOOT-POUNDS}$$

The actual mechanical advantage in this problem as determined from the effort and the load is

$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}}$$

$$= \frac{1{,}200 \text{ POUNDS}}{50 \text{ POUNDS}}$$

$$= 24.$$

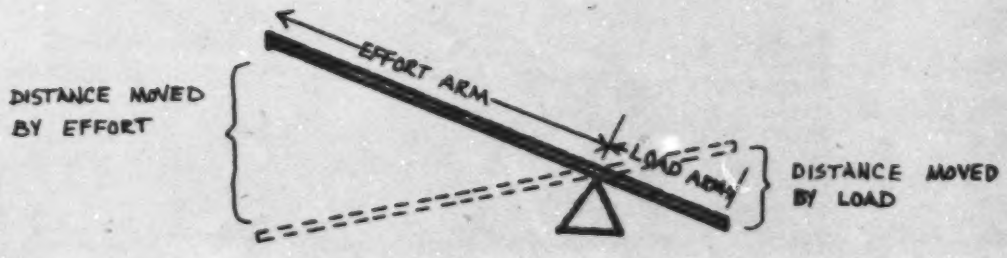
This also happens to be the ratio of the distance moved by the effort to the distance moved by the load,

$$\frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}} = \frac{2 \text{ FEET}}{1/12 \text{ FEET}}$$

$$= 24.$$

This ratio of distance could have been predicted just by looking at the dimensions of the lever in the jack used. The ratio of distance moved by effort to distance moved by load is the same as the ratio of effort arm to load arm.

$$\frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}} = \frac{\text{EFFORT ARM}}{\text{LOAD ARM}}$$

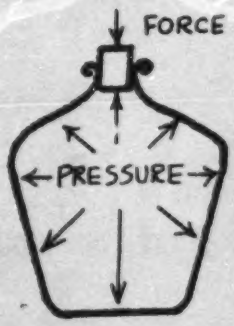


A theoretical value of the mechanical advantage could be found by these steps.

1. Measure the effort arm--the distance from the effort point to the fulcrum,
2. Measure the load--arm the distance from the load point to the fulcrum (also called the resistance arm), and
3. Divide the load arm into the effort arm.

THEORETICAL MECHANICAL ADVANTAGE OF THE HYDRAULIC PRESS

It is also possible to find a theoretical mechanical advantage of the hydraulic press from certain dimensions. The hydraulic press works on the principle that whenever the pressure in a fluid is changed, that change is transmitted throughout the fluid in all directions.

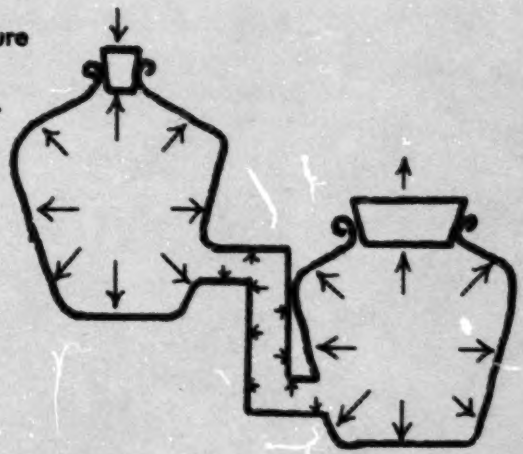


Consider a jug full of water with a loose-fitting stopper. A force applied to the stopper creates an increased pressure in the water. The amount of increase in pressure is found from the definition

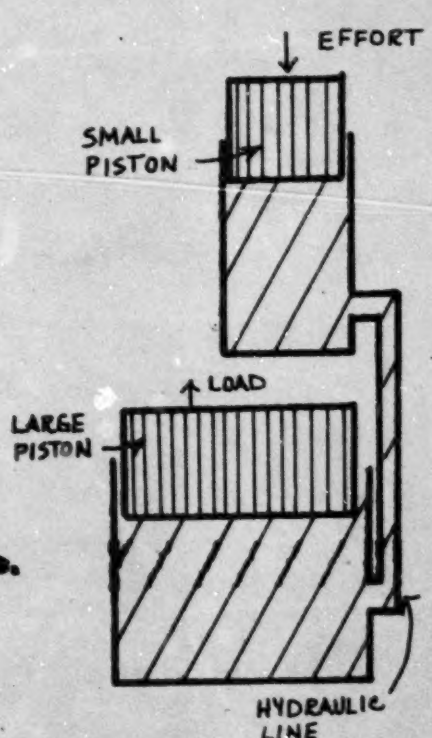
$$\text{PRESSURE} = \frac{\text{FORCE}}{\text{AREA}}.$$

The area here is the area of the bottom surface of the stopper. The pressure created pushes against all inside surfaces of the jug.

If the jug of water is connected to another jug of water by a hose that is filled with water, the pressure increase will be the same in all parts of the system. That means that the stopper in the second jug will experience a pressure under it tending to lift it. A downward force on the first stopper results in an upward force on the second stopper.



Consider a hydraulic system using pistons and cylinders instead of stoppers and jugs. The force applied to the small piston is the effort, and the force at the large piston will lift a load.



Since the pressure is the same in all parts of the system,

$$\frac{\text{EFFORT}}{\text{AREA OF SMALL PISTON}} = \frac{\text{LOAD}}{\text{AREA OF LARGE PISTON}}.$$

Rearranging this statement,

$$\frac{\text{LOAD}}{\text{EFFORT}} = \frac{\text{AREA OF LARGE PISTON}}{\text{AREA OF SMALL PISTON}}.$$

This ratio of load to effort is the mechanical advantage.

So, the theoretical mechanical advantage of a hydraulic press is

$$\text{THEORETICAL MECHANICAL ADVANTAGE} = \frac{\text{AREA OF LARGE PISTON}}{\text{AREA OF SMALL PISTON}}.$$

AUDIO-VISUAL MATERIALS

"Simple Machines and the Concept of Work," a slide-sound program.
"Simple Machines Make Work Easier, a filmstrip.
"Experiments with Simple Machines," a filmstrip.

REVIEW QUESTIONS

1. How does actual mechanical advantage differ from theoretical mechanical advantage?

2. How would you determine the theoretical mechanical advantage of a lever?

3. How would you determine the theoretical mechanical advantage of a hydraulic press?

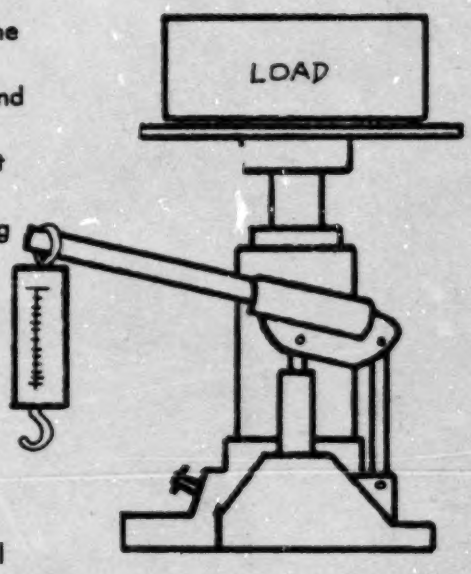
4. What is work?

Do Experiment No. 2 to find the mechanical advantages of two hydraulic jacks.

Experiment No. 2

MECHANICAL ADVANTAGE OF THE HYDRAULIC JACK

In this experiment you will compare the actual mechanical advantages and the theoretical mechanical advantages of two hydraulic jacks. Use the same procedure as you did for the ratchet bumper jack. The three different loads should be as heavy as possible and no less than 50 pounds. Use a handle length of about one foot. Practice lifting each load before measuring the effort to get the "feel" of the jack. The handle should be lowered with a steady, quick motion.



After measuring the effort required to lift three different loads for each jack, take the necessary measurements to calculate the theoretical mechanical advantage for each jack.

Remember that:

$$\text{T.M.A.* of lever} = \frac{\text{effort distance}}{\text{load distance}}$$

$$\text{T.M.A. of hydraulic press} = \frac{\text{area of large piston}}{\text{area of small piston}}$$

$$\text{T.M.A. of hydraulic jack} = \text{T.M.A. of lever} \times \text{T.M.A. of hydraulic press}$$

* T.M.A. means theoretical mechanical advantage.

EXPERIMENT NO. 2 DATA SHEET Name _____

Mechanical Advantage of the Hydraulic Jack

(Show all calculations and answers to questions on a separate sheet.)

I. ACTUAL MECHANICAL ADVANTAGE

Small Jack			Large Jack		
Load (pounds)	Effort (pounds)	Mechanical Advantage	Load (kilograms)	Effort (kilograms)	Mechanical Advantage

II. THEORETICAL MECHANICAL ADVANTAGE

List measurements taken and theoretical mechanical advantage for each jack.

QUESTIONS

1. How did the different loads affect the mechanical advantage?
2. How does the actual mechanical advantage compare with the theoretical mechanical advantage?
3. Why did the mechanical advantages of the two jacks differ?

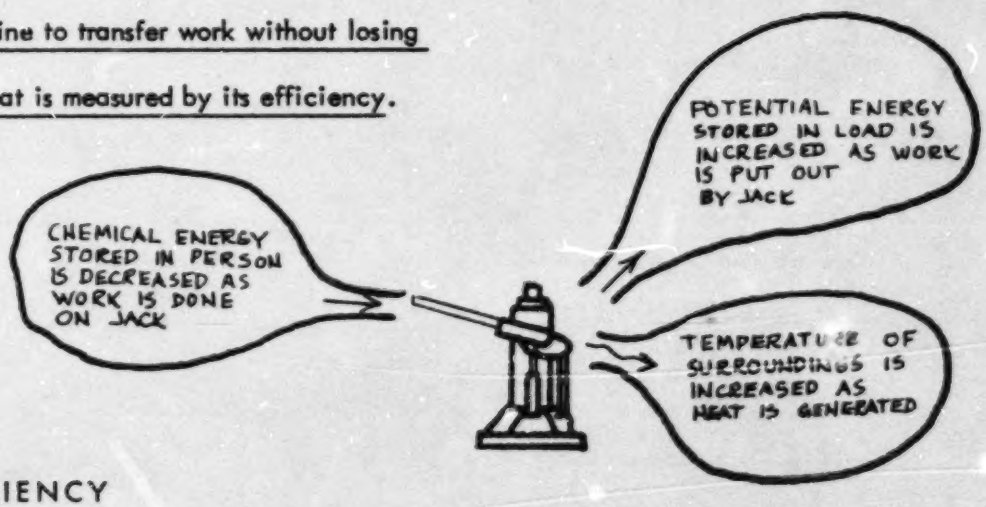
ENERGY

If your measurements were accurate, you found that the actual mechanical advantage is less than the theoretical mechanical advantage. Remember that the theoretical mechanical advantage calculations were based on the assumption that the work put into a machine is equal to the work that comes out of the machine. There must be something wrong with that assumption.

In reality the work done by the jack, or any machine, is less than the work put into it. What happens to the work that disappears?

The explanation of the disappearing work involves a new term--ENERGY. This is one of the most important concepts in physics. For our purposes, energy is the ability to do work and is measured in the same units as work. Although it takes on many forms, the total amount of energy is constant. It can appear as the energy of motion or as heat, electricity, or light. Energy can be stored in a car sitting on a jack, in a stretched rubber band, or in the arrangement of the atoms in such things as food, gasoline, or a charged battery. The energy you received from the food you ate was converted to work as you pushed the jack handle. Part of that energy was put out as work by the jack and part of it--the missing work--was changed to heat.

Part of the input work was changed to heat because of friction between moving parts of the jack. It seems to be an unfortunate fact that everytime work is transferred from one place to another some of it is converted to heat. The ability of a machine to transfer work without losing it to heat is measured by its efficiency.


CHEMICAL ENERGY STORED IN PERSON IS DECREASED AS WORK IS DONE ON JACK
POTENTIAL ENERGY STORED IN LOAD IS INCREASED AS WORK IS PUT OUT BY JACK
TEMPERATURE OF SURROUNDINGS IS INCREASED AS HEAT IS GENERATED

EFFICIENCY

The efficiency of a simple machine is defined as the ratio of the work output to the work input.

$$\text{PERCENT EFFICIENCY} = \frac{\text{WORK OUTPUT}}{\text{WORK INPUT}} \times 100$$

It can also be expressed in terms of mechanical advantage.

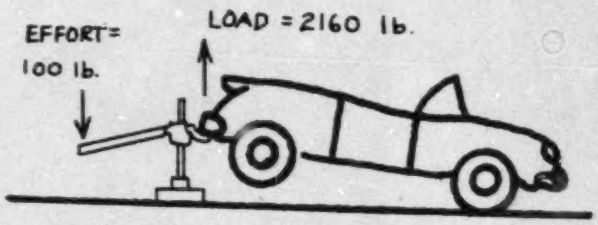
$$\text{PERCENT EFFICIENCY} = \frac{\text{ACTUAL MECHANICAL ADVANTAGE}}{\text{THEORETICAL MECHANICAL ADVANTAGE}} \times 100$$

The actual mechanical advantage is determined by testing the machine.

The ideal situation of maximum efficiency would exist when no work is lost to heat and the output equalled the input. That would be an efficiency of 100 percent. As far as we know an efficiency of 100 percent has never been obtained by a machine.

You would expect that, if some of the work that you did in jacking up a car is lost to heat, you could feel an increase in the temperature of the jack. Consider the following situation.

While jacking up a load of 2,160 pounds a distance of 1 foot, you must push a jack handle down 32 times with a force of 100 pounds. Each stroke of the jack handle is 9 inches so you push downward a total distance of 24 feet. To calculate efficiency,



$$\text{PERCENT EFFICIENCY} = \frac{\text{WORK OUTPUT}}{\text{WORK INPUT}} \times 100$$

$$= \frac{\text{LOAD} \times \text{DISTANCE MOVED BY LOAD}}{\text{EFFORT} \times \text{DISTANCE MOVED BY EFFORT}} \times 100$$

$$= \frac{2{,}160 \text{ POUNDS} \times 1 \text{ FOOT}}{100 \text{ POUNDS} \times 24 \text{ FEET}} \times 100$$

$$= 90\%$$

This means that only 90 percent of the work put into the jack goes into lifting the load. The rest of it is converted to heat by friction in the jack. The work loss to heat was 240 foot-pounds (10 percent of the work input.) This represents enough energy to lift 240 pounds a distance of one foot. However, it will raise the temperature of the jacking mechanism, which weights about 2 3/4 pounds, only one degree Fahrenheit--probably not enough to feel.

AUDIO-VISUAL MATERIALS

"Using Jacks," a slide-sound program.

REVIEW QUESTIONS

1. Why does a simple machine not put out all the work that is put into it?

2. What is efficiency?

3. When a car is sitting on a jack it has more energy than when it was on the ground. Where did the extra energy come from?

4. What could you do to increase the efficiency of a jack?

Do Experiment No. 3 to find the efficiencies of three jacks.

Experiment No. 3

EFFICIENCY OF A JACK

To determine the efficiency of several jacks, collect enough information to use the formula,

$$\text{PERCENT EFFICIENCY} = \frac{\text{WORK OUTPUT}}{\text{WORK INPUT}} \times 100$$

$$= \frac{\text{LOAD} \times \text{DISTANCE LOAD IS MOVED}}{\text{EFFORT} \times \text{DISTANCE EFFORT IS MOVED}} \times 100.$$

Determine the efficiency of the ratchet bumper jack and two hydraulic jacks. Use loads of approximately 50 pounds and 100 pounds.

EXPERIMENT NO. 3 DATA SHEET Name _____

Efficiency of a Jack
(Show all calculations and answers to questions on a separate sheet.)

	Load (Pounds)	Load Distance (Feet)	Effort (Pounds)	Effort Distance (Feet)	Work Out (Ft.-lb.)	Work in (Ft.-lb.)	Efficiency
Ratchet Bumper Jack							
Small Hydraulic Jack							
Large Hydraulic Jack							

QUESTIONS

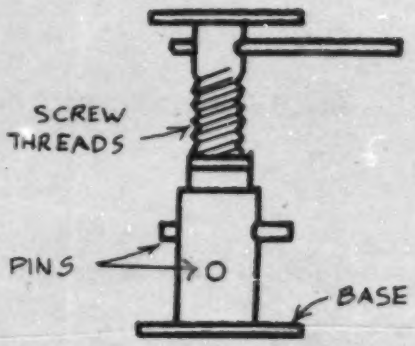
1. How did the amount of load affect the efficiency?

2. Which jack was most efficient?

3. Does the amount of work that a jack loses to heat increase as the jack lifts larger loads?

IV. THE SCREW JACK

Using an inclined plane to lift an object is like climbing stairs instead of a vertical ladder. Using a screw to lift an object is like climbing a circular staircase. A screw is an inclined plane wrapped around a cylinder.



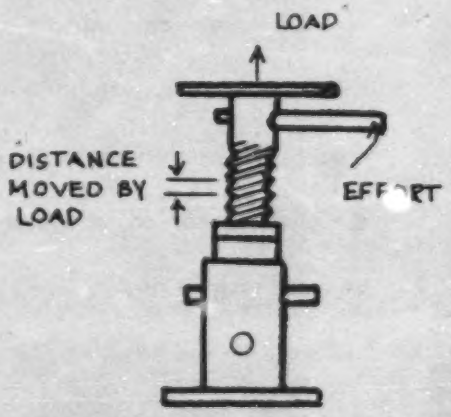
The screw is a simple machine because it enables us to lift a heavy load a short distance by exerting a small force over a large distance. The theoretical mechanical advantage can be found by considering the work input as being equal to the work output.

WORK INPUT = WORK OUTPUT

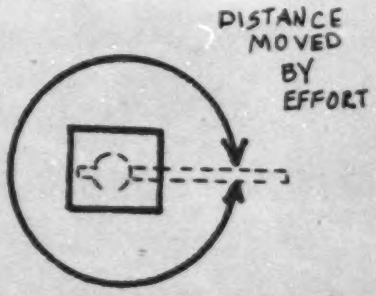
EFFORT X DISTANCE MOVED BY EFFORT = LOAD X DISTANCE MOVED BY LOAD

$$\frac{\text{LOAD}}{\text{EFFORT}} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}}$$

The ratio of distances is the theoretical mechanical advantage. Moving the jack handle completely around the jack one time causes the load to be lifted the distance between two adjoining threads of the screw. The distance between two adjoining threads is called the pitch.



Consider a screw jack with a handle one foot long and with ten threads per inch. The distance moved by the effort is the circumference of a circle with a radius of one foot.



TOP VIEW

DISTANCE MOVED BY EFFORT = 2 X π X 1 foot

= 6.28

If there are ten threads per inch the distance between two adjoining threads is 0.1 inch.

$$\text{THEORETICAL MECHANICAL ADVANTAGE} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}}$$

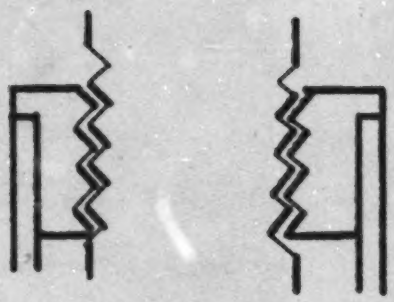
$$= \frac{6.28 \text{ feet}}{0.1 \text{ inch}}$$

$$= \frac{75.36 \text{ inches}}{0.1 \text{ inch}}$$

$$= 753.6$$

The screw jack appears to be capable of a much higher mechanical advantage than a normal size ratchet bumper jack or hydraulic jack. Since the screw jack is used to lift much heavier loads (such as houses) than the other jacks, it should have a higher mechanical advantage. The advantage is not as large as it seems, however, because of friction.

The screw jack has relatively large surface areas that rub together when the jack is in operation. As the load is increased, these surfaces are pressed together harder--increasing the friction losses. Thus, the actual mechanical advantage of the screw jack remains about constant as the load is increased. The large frictional loss causes the screw jack to be inefficient.



Friction is not altogether bad, though. It is what keeps the screw jack in the raised position even when a very heavy load is pushing down on it. Jacks need a method for keeping the load up after it has been raised. They need to prevent the load from doing work on the jack. The ratchet bumper jack has a ratchet that falls into a notch in a ratchet bar and holds the load in place. The hydraulic jack uses check valves that allow the hydraulic fluid to flow in one direction only. To allow the hydraulic fluid to leave the large cylinder, a manual valve must be opened. The additional friction of the screw jack serves the same purpose as the ratchet of the bumper jack and the check valve in the hydraulic jack. This friction prevents the backward "flow" of work.

Do Experiment No. 4 to find the mechanical advantage and efficiency of a screw jack.

Experiment No. 4

MECHANICAL ADVANTAGE AND EFFICIENCY OF THE SCREW JACK

The actual mechanical advantage of the screw jack is easily determined by measuring the effort required to lift a known load. Use loads of roughly 50, 75 and 100 pounds and jack handle lengths of 6, 12 and 18 inches.

Due to slight imperfections in the screw threads, the effort will vary somewhat for different heights of the jack. To avoid this variation find a height at which the screw turns freely and make all your measurements at that point. Turn the screw about one-half revolution; then back it up and turn it again. Take all your measurements several times and record the most consistent reading.

First take measurements for each jack handle length with a well oiled screw. Then take the measurements using the longest jack handle again after removing the oil from the screw. Use a solvent such as kerosene or carbon tetrachloride to remove the oil.

Also calculate the theoretical mechanical advantage and efficiency of the jack you used.

EXPERIMENT NO. 4 DATA SHEET Name _____

Mechanical Advantage and Efficiency of the Screw Jack

(Show all calculations and answers to questions on a separate sheet.)

	6 inch handle		12 inch handle		18 inch handle	
Load (Pounds)	Effort (Ounces)	Mechanical Advantage	Effort (Ounces)	Mechanical Advantage	Effort (Ounces)	Mechanical Advantage
					Oil	
					Dry	
					Oil	
					Dry	
					Oil	
					Dry	
Average Mechanical Advantage						Oil
						Dry
Theoretical Mechanical Advantage						
Efficiency						Oil
						Dry

QUESTIONS

1. How does the mechanical advantage vary as the jack handle length is increased? Why?

2. In what other way could the mechanical advantage be changed?

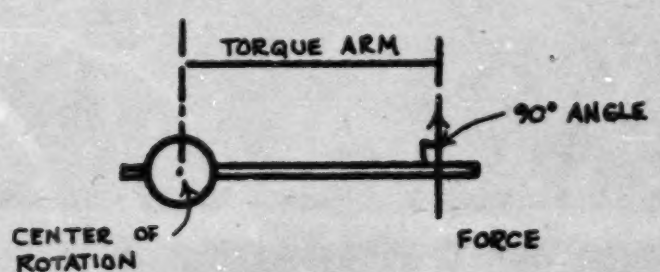
3. How does the oil affect the efficiency? Why?

4. How does the efficiency of the screw jack compare to the ratchet bumper jack and hydraulic jack?

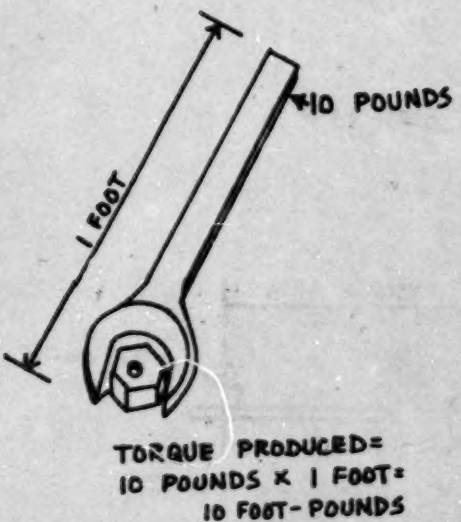
TORQUE

While operating the screw jack you were exerting a force that was causing a rotating motion. The measure of the turning effort of a force is called TORQUE. The amount of torque you produced was equal to the effort, or force, you exerted times the length of the jack handle. To be more exact, the length of the jack handle is called the torque arm and is the perpendicular distance from the force to the center of rotation. When force is measured in pounds and the torque arm in feet, torque is measured in foot-pounds. When force is measured in kilograms and the torque arm in meters, torque is measured kilogram-meters.

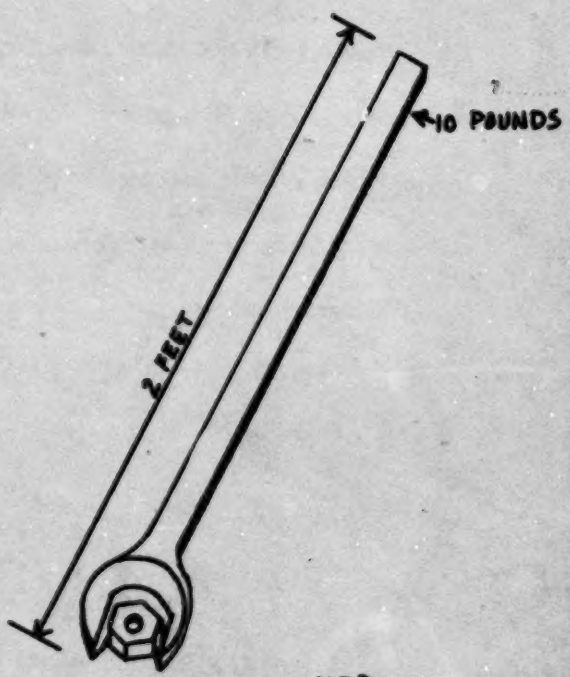
TORQUE = FORCE X TORQUE ARM



In order to exert a larger torque, and therefore have more turning power, you must exert a larger force or use a longer torque arm. Less effort was required to operate the screw jack when a longer torque arm was used. Doubling the length of the torque arm allows you to produce twice as much torque without increasing your effort. You take advantage of this fact when you use wrenches with long handles and screw drivers with large diameter handles.



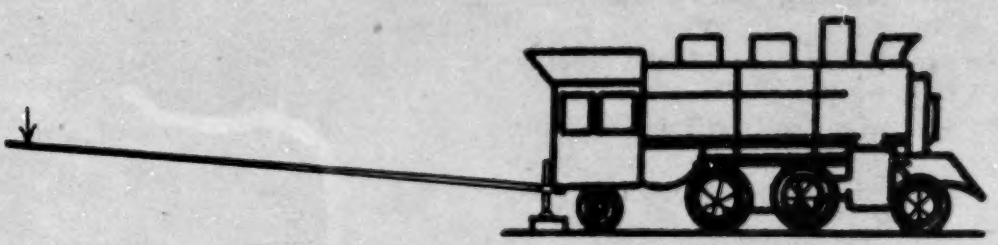
TORQUE PRODUCED=
10 POUNDS x 1 FOOT=
10 FOOT-POUNDS



TORQUE PRODUCED=
10 POUNDS x 2 FEET=
20 FOOT-POUNDS

V. LOAD LIMITATIONS

You may have noticed that each of the jacks that you used is rated to lift a certain maximum load. What determines the maximum load that a jack can lift? Why can't you use a bumper jack to lift a locomotive if the lever is long enough to give you a very large mechanical advantage?



A jack cannot be used to lift more than its rated load without the risk of some part of the jack breaking. An understanding of load limitations requires some knowledge of how materials act under load.

The strength of a solid material depends upon how difficult it is to separate the atoms or molecules of the material. Consider two meials--steel and aluminum. Steel is stronger than aluminum because the atoms in the steel are harder to separate than the atoms in the aluminum. However, a large piece of aluminum will support more weight than a very small piece of steel. So when we speak of the strength of a material instead of saying it will support so many pounds, we say it will support so many pounds per square inch of cross-sectional area. This brings up a new term--STRESS.

STRESS

When a material is lifting a load, that material is put under a stress. The amount of stress is equal to the weight of the load divided by the cross-sectional area of the material.

$$\text{STRESS} = \frac{\text{FORCE}}{\text{AREA}} .$$

The area is always the cross-sectional area of the material under stress.

Consider a 1/4-inch-diameter steel rod that supports a load of 2,000 pounds. The cross-sectional area is the area of the circle you would have if you cut the rod at right angles to its length. It would be a circle with a diameter of 1/4 inch and an area of about 0.05 square inches.

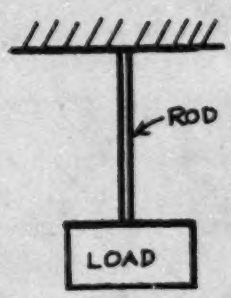
$$\text{STRESS} = \frac{\text{FORCE}}{\text{AREA}}$$

$$= \frac{2{,}000 \text{ lbs.}}{0.05 \text{ sq. in.}}$$

$$= \frac{40{,}000 \text{ lbs.}}{\text{sq. in.}}$$

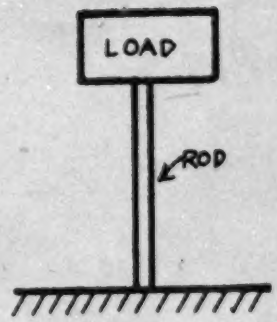
$$= 40{,}000 \text{ psi}$$

Before we can predict whether or not the rod will break, it is necessary to know what kind of stress is involved. We will consider three types of stress: stress under tension, stress under compression, and shear stress. A material under tension tends to become longer. When a material is unde compression, it becomes shorter. Shear stress tends to shear, or cut, the material.

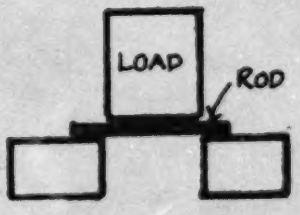


TENSION

The maximum stress that a material can withstand before breaking is called the ultimate strength. The ultimate strength of a piece of metal depends upon its composition--the elements that it contains--and the way in which it was made. Table I lists the ultimate strength for some commonly used metals. The figures are approximate for particular alloys. Exact figures would take into account the way in which the metal was formed into its final shape.



COMPRESSION



SHEAR

METAL	ULTIMATE STRENGTH (THOUSANDS OF PSI)		
	TENSION	COMPRESSION	SHEAR
WROUGHT IRON	47	47	38
AISI 1020 STEEL (STRUCTURAL STEEL)	65	65	50
AISI 1045 STEEL	95	95	70
AISI 1095 STEEL	142	142	105
AISI 2340 STEEL	135	135	100
302 STAINLESS STEEL	140	140	110
CAST IRON CLASS 20	20	80	32
CAST IRON CLASS 40	40	125	55
CAST IRON CLASS 60	60	170	65
RED BRASS	57	---	37
YELLOW BRASS	61	---	40
175 ALUMINUM ALLOY	62	---	38
245 ALUMINUM ALLOY	68	---	41
MONEL	80	---	56
AZ31X MAGNESIUM ALLOY	40	---	19

TABLE I. ULTIMATE STRENGTHS OF SOME METALS

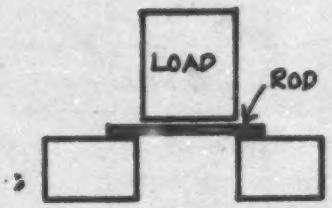
Consider a sample of structural steel with a tensile strength of 65,000 psi, a compressive strength of 65,000 psi, and a sheer strength of 50,000 psi. To calculate the force necessary to break a 1/4-inch-diameter rod made of this steel we use the realtionship

FORCE = STRESS X AREA.

For a tension load or compression load,

$$\text{FORCE} = 65{,}000 \frac{\text{lb.}}{\text{sq. in.}} \times .05 \text{ sq. in.}$$

$$= 3{,}250 \text{ POUNDS.}$$



SHEAR

For a shear load, (assume that the load is supported as shown so the effective area of the rod is twice as much as before.)

$$\text{FORCE} = 50{,}000 \frac{\text{lb.}}{\text{sq. in.}} \times .10 \text{ sq. in.}$$

$$= 5{,}000 \text{ POUNDS.}$$

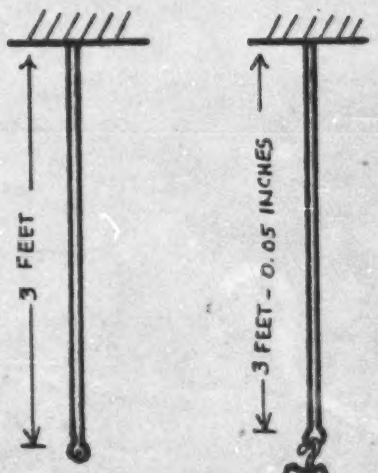
Metals can be damaged by loads much less than the breaking force. They can be stretched or bent out of shape. If a metal is under tension or compression, its length changes; if it is under shear, its shape changes--no matter how small the stress.

ELASTICITY

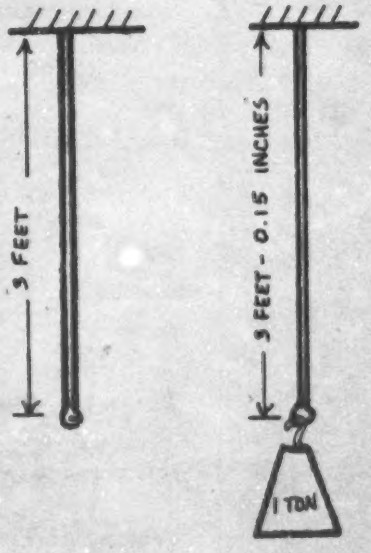
Metals are elastic. That means when a tension load is applied, the metal stretches; when the load is removed, it returns to its original length. The greater the load, the greater the stretch. A long piece of metal will stretch further than a short piece under the same stress.

The amount of stretch in strong metals such as steel is usually so small it is not noticed. Consider the 1/4-inch-diameter steel rod supporting a tension load of 2,000 pounds. If the rod were three feet long, the increase in length due to stretch would only be about 0.050 inches. If the original length were ten times as much, the amount of stretch would be ten times as much. An aluminum rod of the same size and with the same load would stretch three times farther than the steel rod.

If a metal is stretched too far, it will not return to its original length when the load is removed. We say it has reached its elastic limit and is permanently deformed. So, while it is undesirable for a metal piece to break under load, it is also undesirable for it to reach its elastic limit. The stress necessary to exceed the elastic limit is in the range of 1/2 to 2/3 the stress that will cause breakage.



1/4 INCH STEEL ROD



1/4 INCH ALUMINUM ROD

LOAD LIMITATIONS ON HYDRAULIC SYSTEMS

Increasing the load being lifted by a hydraulic jack increases the pressure in the hydraulic fluid. All parts of the system that come into contact with the hydraulic fluid experience essentially the same pressure. Therefore, the maximum pressure allowable is determined by the weakest part of the system. Those parts include the cylinder walls, hydraulic lines, seals, gaskets, couplings, and valves.

Consider a hydraulic jack with a maximum load rating of ten tons.

If, the large piston has a diameter of two inches, the maximum pressure in the hydraulic fluid is found as follows:

$$\text{PRESSURE} = \frac{\text{FORCE}}{\text{AREA}}$$

$$= \frac{20{,}000 \text{ POUNDS}}{3.14 \text{ sq. in.}}$$

$$= 6{,}366 \text{ psi.}$$

All parts of the hydraulic system must be able to withstand this pressure. Actually they should withstand somewhat more because of a built-in safety factor.

SAFETY FACTORS

The safety factor is the ratio of ultimate load to allowable load. Ultimate load is the largest load a particular piece of material can stand before it breaks. Allowable load is the largest load that a piece of material can safely be subjected to.

The 1/4-inch diameter steel rod considered earlier was found to be able to lift 3,250 pounds before breaking. In actual practice that rod might be rated to lift only 650 pounds. In that case the safety factor would be found by

$$\text{SAFETY FACTOR} = \frac{\text{ULTIMATE LOAD}}{\text{ALLOWABLE LOAD}}$$

$$= \frac{3{,}250 \text{ POUNDS}}{650 \text{ POUNDS}}$$

$$= 5.$$

Once the ultimate load is known and a safety factor is chosen, the allowable, or rated load, for a specific piece of material can be determined.

The safety factor to be used for a piece of material that will be subjected to a load depends on several things. Some them are:

1. The degree of safety required. What dangers to life and property are involved?
2. The degree of economy desired. It would be desirable to use a high percentage of the strength of expensive materials.
3. Dependability of the material. Are defects easily found? Do similar pieces of the material behave the same? Does the material give warning of failure? (Hard, brittle materials break without warning while tough materials deform or stretch and thus give a warning)
4. Load conditions. Is material subjected to steady, changing, or shock loads?

A safety factor of 2 might be enough for a material under steady load if failure would not endanger life or property. A safety factor of 10 might be required if the material were subjected to shock loads and if failure would endanger life or property.

AUDIO-VISUAL MATERIALS

"Load Limitations", a slide-sound program.
"Behavior of Structural Materials", a 16mm film.

REVIEW QUESTIONS

1. What is stress? What are three types of stress?

2. What is the difference between elastic limit and ultimate strength? Which is larger?

3. Which is the strongest metal listed in Table 1? Which is the weakest?

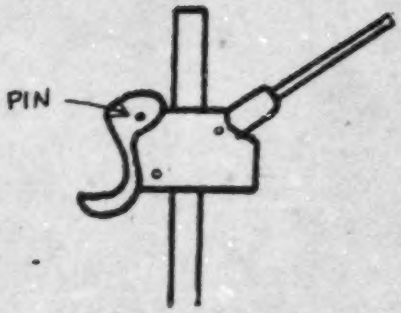
4. What does elasticity have to do with safety factor?

Experiment No. 5

LOAD LIMITATIONS ON JACKS

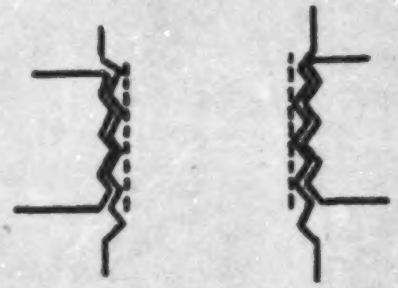
In this experiment you will take measurements and perform some calculations to determine

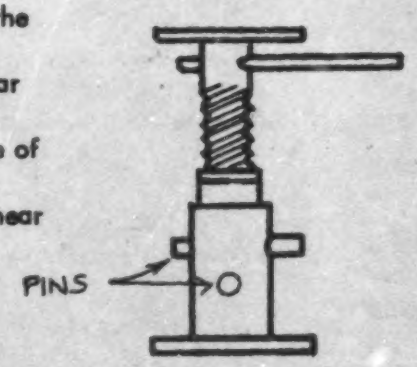
1. the stress developed in a ratchet bumper jack by its rated load, (if the load rating is unknown, assume 1 1/2 tons)
2. the pressure developed in two hydraulic jacks subjected to their rated load, and
3. the maximum load a screw jack will support.



Assume that the weakest part of the ratchet bumper jack is the pin that connects the lifting hook to the lifting mechanism. Examine the stresses in that pin.

The screw jack will be examined for stress at two points. First, assume that the screw is the weakest point and an excessive load would strip, or shear, the screw threads off. The area of shear in that case is the lateral surface area of a cylinder. The height of the cylinder is equal to the thickness of the nut on the screw. For the other stress point, consider the load necessary to shear the two pins in the screw jack. Assume that the type of steel that the screw and the pins are made of has a shear strength of 50,000 psi.





Experiment No. 5 Data Sheet Name _____

Load Limitations on Jacks

(Show all calculations and answers to questions on a separate sheet.)

I. THE RATCHET BUMPER JACK

Load rating of jack _____

Type of stress involved _____

Area over which stress is applied _____

II. THE HYDRAULIC JACKS

Load rating of jack _____ Load rating of jack _____

Area of large piston _____ Area of large piston _____

Pressure due to rated load _____ Pressure due to rated load _____

III. THE SCREW JACK

Type of stress involved _____

Area over which stress is applied (Screw threads) _____

Area over which stress is applied (Two pins) _____

Maximum load threads will support _____

Maximum load two pins will support _____

QUESTIONS:

1. If the supporting pin in the ratchet bumper jack were made of 1/4-inch-diameter type 302 stainless steel, how large a load would the jack support? _____ (Use Table I)

2. If the hydraulic line in a hydraulic lift will withstand 10,000 psi of pressure, how large a load will the lift support? The diameter of the large piston is 4 inches.

_____

3. Determine the safety factor used if the pin in the ratchet bumper jack were made of AISI 1045 steel. (Use Table I) _____

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